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CONTROLLING IMPULSE NOISE HAZARDS: PROGRAMMATIC MODEL FOR DEVELOPING VALIDATED EXPOSURE STANDARDS (Reprint)

By

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20. Abstract

Blast-producing weapons such as artillery cannons, mortars, and rockets can produce serious hearing loss among combat troops. Effective control of the risks of hearing loss requires realistic, valid standards for noise hazard evaluation and materiel design. Unfortunately, current Army standards for impulse noise are neither founded on a thorough scientific database nor validated for operational scenarios. These limitations make it difficult to balance the requirement for improved weapons against the need to protect crewmembers' hearing. In support of the Army's Health Hazard Assessment Program, a multiphase research model has been developed to provide a scientific foundation for valid impulse noise standards. The model constitutes a blueprint of the programmatic building blocks required to achieve the ultimate goal of realistic, effective standards applicable to a broad spectrum of weapons. Laboratory and field research methods are used to establish a systematic, comprehensive database relating auditory injury to critical noise parameters. The model culminates in validation of new standards under realistic field conditions. Implementing the model requires long-term research commitments in executing the program. Once established, the new noise exposure standards can be translated into hearing conservation standards, materiel design standards, and noise hazard assessment procedures. These new tools will permit Army developers to design new blast-producing weapons which are, at the same time, safer and more effective.

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CONTROLLING IMPULSE NOISE HAZARDS: PROGRAMMATIC MODEL FOR DEVELOPING VALIDATED EXPOSURE STANDARDS (U)

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Among the health hazards posed by Army weapon systems, one of the most serious and pervasive is the threat of hearing loss from blast overpressure. Current Army weapons development efforts aimed at countering Warsaw Pact threat capabilities include improved artillery cannons, antitank weapons, and mortars. New artillery cannons and propellant charges are being developed to meet doctrinal requirements for enhanced delivery range, rapid rates of fire, and reduced weight for air mobility. Improved antitank weapons with high energy propellants may be fired from reflective enclosures such as bunkers, covered foxholes, and urban structures. Mortar technology is being advanced to achieve greater delivery ranges and rapid rates of fire. In each of these families of weapons, dangerously high levels of blast overpressure are a byproduct of advancing weapons technology.

High levels of impulse noise, which will be commonplace on the modern battlefield and on training ranges, seriously threaten the hearing of soldiers operating blast-producing weapons. Hearing loss, even temporary, can degrade critical soldier performance, endanger effective command, control and communications, and disrupt critical combat tasks such as detecting the enemy during patrol missions. Thus, hearing loss can jeopardize the soldier's capability to accomplish the combat mission.

Accurate hearing protective criteria are essential to a balanced resolution of the competing requirements to increase combat capabilities through improved weapons and to preserve combat effectiveness through conserving the soldier's hearing. In general, three different types of criteria are used to limit exposure to hazardous entities -- damage risk criteria, medical exposure limits, and materiel design standards.

Damage risk criteria are comprehensive statements of the relationships between critical parameters of hazardous entities (e.g., impulse noise) and the probability of injury of various degrees. They are characterized by their statements about the probability of specified injury resulting from specified exposure conditions in set proportions of the at-risk population. Ideally, damage risk criteria

should serve as the bases for developing medical exposure limits and materiel design standards. Thus they form the foundation for working documents used to protect crewmembers' health and insure system effectiveness. Currently, there is no true damage risk criterion for impulse noise.

Medical exposure limits are thresholds which, when exceeded, call for the use of protective measures to limit the proportion or extent of injury in the at-risk population. They should be derived from damage risk criteria by adopting acceptable rates of occurrence for the various degrees of injury and finding the associated exposure conditions. This requires value judgments as to what constitutes acceptable proportions and degrees of injury. The Army's current medical exposure limit for impulse noise is TB MED 501 (1), which incorporates the Army's materiel design standard by reference.

Materiel design standards provide specific limits for hazardous entities for use by materiel designers and manufacturers. These limits constitute specifications which must not be exceeded if the materiel is to be acceptable to the procuring activity. In general, they should not allow equipment to produce the hazardous entities in excess of the medical exposure limits. They normally will be a conservative simplification of the medical exposure limits and may include a tolerance factor for design and manufacturing uncertainty. The Army's materiel design standard for impulse noise is MIL-STD-1474B(MI) (2).

MIL-STD-1474 is today the noise standard for the design of Army weapons and for the determination of auditory hazards from impulse noise. However, it is based on a totally inadequate biomedical data base and on a number of assumptions which have yet to be validated. This standard has its origins in the proposed "damage risk criterion" (3) published by the National Research Council's Committee on Hearing, Bioacoustics and Biomechanics (CHABA) in 1968. In spite of its title, the CHABA proposed criterion is, at best, a medical exposure limit. This criterion is based primarily on data from small arms noise. The authors of the CHABA document recognized that the database available at that time was limited. Accordingly, they wrote, "While these [limit] curves do no great violence to the published data on either TTS [temporary threshold shift] or PTS [permanent threshold shift] from impulse noise ... they admittedly represent only a first attempt at a reasonable DRC for exposures to impulse noise. Parameters that are ignored in the present criterion may eventually be shown to be important." The CHABA criterion also proposes a rule for trading allowable number of impulses for intensity in an exposure. This rule represents the "educated guess" of Coles et al. (4). The criterion does not specify procedures to account for the effects of hearing

protection. Finally, it is assumed that limiting TTS will limit permanent hearing loss. This has not been empirically documented.

MIL-STD-1474 was derived by raising the CHABA criterion by 29 dB in an attempt to account for the protection afforded by hearing protective devices (5). The 29 dB factor came from a single study (6) using earplugs and was arbitrarily assumed to apply to all single hearing protectors, whether earplugs or earmuffs, regardless of the actual efficacy of the protector. In addition, it was assumed that the use of earplugs and earmuffs together would increase protection by 6.5 dB. These hearing protection factors have never been validated.

The fundamental need for a revised, validated impulse noise DRC has been recognized since 1976, when potential noise hazards were identified for the Army's new M198 howitzer. The questions raised by this system highlighted the inadequacy of the existing standard for resolving issues of impulse noise hazards. In particular, there was no way to predict whether available hearing protection would be adequate for the M198, because of the lack of a valid DRC. In the ensuing years, similar issues arose for a host of other weapon systems, underscoring the need for new standards applicable to the full range of diverse blast producing weapons.

In early 1977 a multifaceted impulse noise research program was established to develop, in part, a comprehensive foundation for a validated DRC. To provide a blueprint for this program, a model was created to guide the systematic development of a thorough scientific database. Unable to locate a relevant model in the life sciences literature, a novel planning approach was adopted to link the ultimate goal to specific research requirements. In order to achieve the ultimate goal of a validated DRC, rules for predicting injury from both protected and unprotected exposures must first be available. In turn, prediction rules cannot be developed until there exists a database relating quantifiable exposure parameters to patterns of auditory injury. Finally, development of the database requires a host of research tools including instrumentation, facilities, and methods.

This process resulted in a model (Figure 1) incorporating five categories of research activities: development of research tools, establishment of a comprehensive database, development of injury prediction rules, DRC derivation, and DRC validation. This model identifies the building blocks necessary and sufficient to achieve the ultimate goal of realistic, effective standards applicable to a broad spectrum of weapons. The elements within the model are not strictly sequential. Some can proceed in parallel, especially during tool development and database establishment. In general, elements

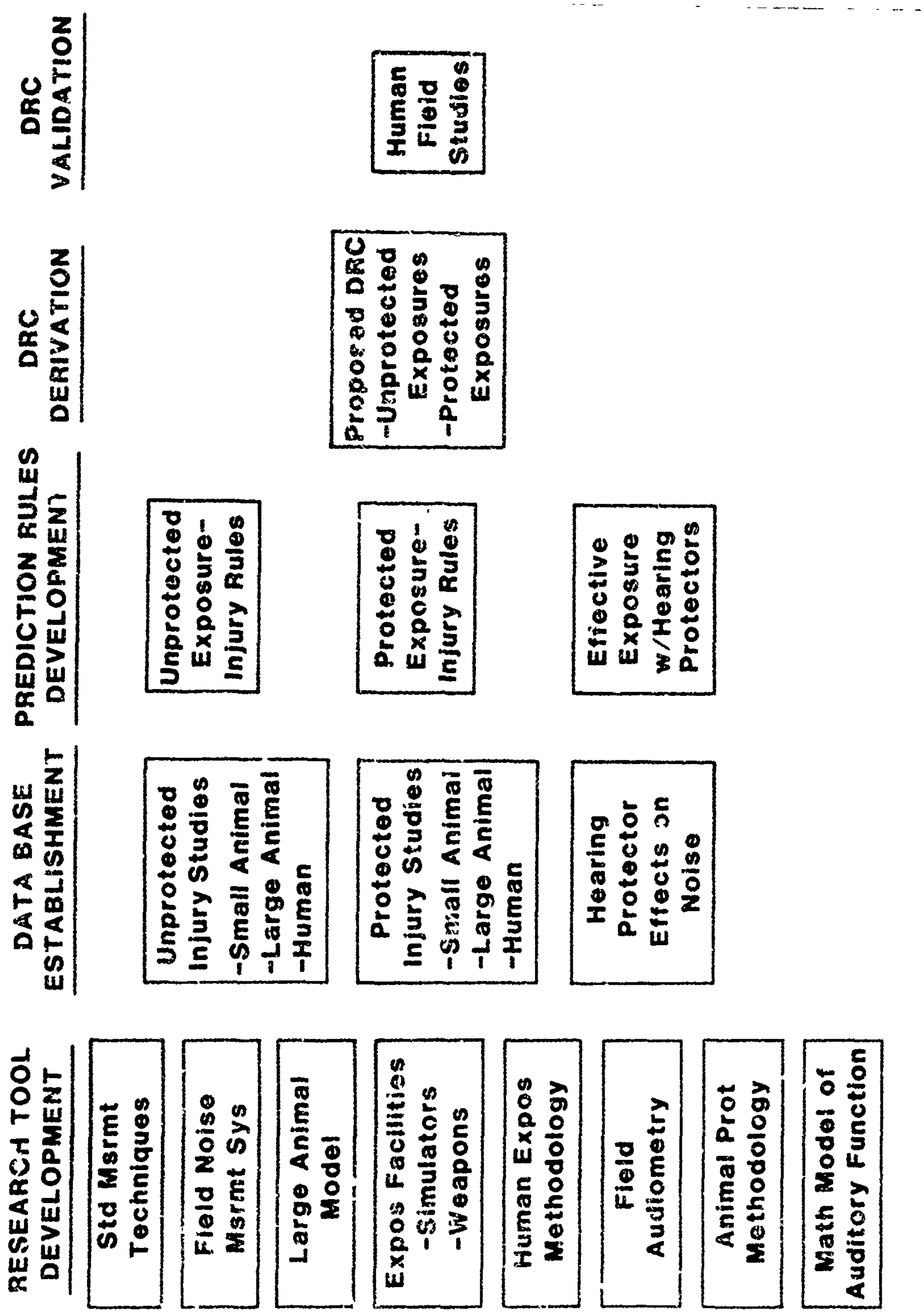

FIGURE 1. Schematic representation of programmatic model for developing valid impulse noise damage risk criterion.

regarding unprotected ears will precede those relating to protected ears.

The cornerstone of the efforts to develop a valid DRC is the comprehensive database tailored to the specific program objectives. The available data definitively relating impulse noise to auditory injury were extremely limited at the outset. This provided a rare opportunity to systematically design the structure of the necessary and sufficient database to support development of a realistic DRC. A logical analysis identified a number of fundamental issues requiring resolution in order to answer practical questions related to safe operation of weapons. These issues are: (a) Which physical noise parameters are critical determinants of injury? (b) By what rule should number of impulses be traded for intensity? (c) What is the effect of temporal spacing of impulses? (d) How do mixtures of different impulses relate to injury? (e) What is the relationship between physical noise parameters and probability of injury? (f) How do hearing protectors influence injury? (g) What is the relationship between temporary and permanent hearing loss?

From these issues were derived a number of research variables requiring empirical data: peak pressure, distribution of energy across frequency, impulse duration, rise time, impulse complexity, angle of incidence, number of impulses, temporal spacing of impulses, combinations of different impulses, and hearing protection. In devising an actual research plan, it was decided to address the various research variables in unprotected and protected ears in separate phases. Each phase includes systematic investigation of the effects of impulse noise on hearing in small animals, large animals, and humans using a mixture of laboratory and field experiments. These experiments focus on temporary and permanent threshold shifts as indicators of hearing impairment and on histological measures of cochlear damage. A separate effort was designed to quantify the attenuating effects of hearing protectors on impulse noise, to provide a basis for scaling between protected and unprotected exposures.

Of the research tools needed to establish the biomedical database, a few already were available. These included small animal models (cat, chinchilla, guinea pig), behavioral and electrophysiological audiometry methods, limited laboratory and field exposure facilities, and cochlear histological evaluation methods. To complete the complement of research tools, the following major items were required: (a) impulse noise measurement techniques standardized across different evaluation agencies; (b) an impulse noise measurement system capable of being used in the field; (c) at least one large animal model of auditory injury; (d) a variety of exposure facilities, including actual weapons and weapons noise simulators; (e) methodology

for exposing human volunteers to hazardous impulse noises; (f) a field audiometry system suitable for monitoring several volunteers at a time; (g) methodology for testing hearing protectors in animals; and (h) a mathematical model of auditory system function applicable to animals and humans.

As the biomedical database matures, systematic sets of data quantitatively relating specific exposure parameters to degrees and probabilities of injury will become available. Using these sets of data, development of injury prediction rules can begin with the derivation of functions similar to dose-response curves. These functions permit the identification of those exposure variables which are critical determinants of injury. These critical exposure variables will be incorporated in a comprehensive formulation of the exposure-injury relationships. This formulation may take the form of a multivariable mathematical model or a set of equations with rules for application. Alternatively, it may take the form of a cochlear model incorporating mechanisms of both temporary and permanent injury. Comprehensive exposure-injury formulations will be developed for both unprotected and protected ears.

The database will include sets of data relating characteristics of hearing protectors to the critical exposure variables. From these relationships will be derived a set of equations which will predict effective exposure when hearing protectors are used. This will permit estimates of noise hazards to take into account hearing protectors with different characteristics. The prediction rules resulting from these efforts will provide a realistic basis for using measured physical parameters of impulse noise to predict varying degrees of injury with different levels of hearing protection.

In developing the proposed DRC, the prediction rules developed above for unprotected exposures, protected exposures, and hearing protector effects will be integrated. The heart of the DRC will be the provisions for assessing hazards of unprotected exposures. Procedures will be specified for determining effective exposures when hearing protectors are worn. These effective exposures then will be evaluated using the provisions for assessing unprotected exposures. As currently envisioned, the proposed DRC will be applicable to all families of blast-producing weapons and all operational conditions.

The final stage of the model is validation of the proposed DRC. This stage is necessary to determine if the DRC ultimately works in practice. Human exposure methodology will be used to study troops operating actual weapons under realistic operational conditions. A representative selection of different weapons will be required, along with a variety of hearing protectors. Based on the results of the

validation studies, adjustments to the proposed DRC will be made, as appropriate.

The conclusion of the validation stage will complete the research activities necessary to establish an empirically based impulse noise DRC. Once validated, the proposed DRC will be ready to hand off to the appropriate policy setting agency for finalization, approval, and publication.

Since the establishment of the program, substantial progress has been made in implementing the model. Many of the tools missing at the outset are in place or under development now. The various US Army organizations involved in impulse noise measurement have established common methodology (7). A NATO study group is nearing completion of a guideline to help insure comparability of noise data. A computer-based, mobile, high-speed data acquisition system has been designed and constructed to measure impulse noise in the field. Laboratory exposure facilities now available include high intensity speakers, a compressed air shock tube, and spark gap generator. Safe techniques have been developed to use bare explosive charges for freefield and reverberant exposures. Specialized methodology for safely exposing human volunteers to actual weapons noise or bare explosive charges has been used successfully (8,9). A mobile audiometric test facility has been designed and constructed (10); this provides the capability to obtain simultaneous audiograms on four individuals in the field. Foam earplugs have been designed and fabricated for the chinchilla's ear.

In parallel with efforts to develop research tools, a number of small animal and human studies represent the beginning of the database development. Chinchilla studies using unprotected exposures have evaluated the role of peak pressure (11) and number of impulses (12) in producing hearing loss and cochlear damage. Additional chinchilla studies assessing the effects of temporal spacing of impulses, distribution of energy across frequency, and combinations of different intensities are underway, again with unprotected exposures. Protected exposure studies using human volunteers have been conducted with the M198 howitzer (8) and the VIPER antitank weapon (9). While these studies were designed to determine the adequacy of available hearing protectors, their results contribute useful information to the database. Finally, human volunteers served in an extensive field and laboratory evaluation of the effects of various hearing protectors on different types of simulated weapons noise. These results will contribute to the database on the influence of hearing protectors on critical parameters of impulse noise.

Despite the significant progress already achieved, much remains to be done in completing the research outlined in the model. The

large-scale, parametric projects required to establish the systematic, comprehensive database demand long-term research commitments. Until a complete database is available, a valid impulse noise DRC cannot be established.

Once established and validated, the new impulse noise DRC will need to be translated into working documents which are useful to combat developers, materiel developers, test and evaluation agencies, health hazard assessment organizations, hearing conservation personnel, and medical policy proponents. This follow-on phase will consist primarily of revising or updating existing documents, including the medical exposure limit, the materiel design standard, test and evaluation procedures, health hazard assessment procedures, and guidelines for combat developers. Armed with these powerful new tools, Army developers will be able to design and produce new blast-producing weapons which are, at the same time, safer and more effective.

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